Application of Kalman Filter for Disturbance Storm Time ($D_{st}$) Index Estimation

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Outline:

• Space weather effects
• Model based $D_{st}$ index estimation
• Kalman filter (KF) techniques (EKF& UKF) based $D_{st}$ index estimation
• Implementation
• Results
• Conclusions
Space weather effects

- Damage to spacecraft electronics
- GPS signal scintillation
- GIC in power systems
  - and etc.

Geomagnetic indices

- AE, AU, AL
- Kp
- Ap
- $D_{st}$
Model based $D_{st}$ index estimation

Solar wind parameters

$D_{st}$ model

Estimated $D_{st}$

final $D_{st}$

Error
$D_{st}$ index data

- **quicklook $D_{st}$**: nearly real-time but noisy
  - $t = 0$
  - 15 min

- **provisional $D_{st}$**: check once/more to increase accuracy
  - 4-10 months

- **final $D_{st}$**: accurate data
  - 1-5 years
If Yes, how to deal with it (noisy data)?

Can Kalman filter handle this?

!!Think!!

Is it possible to use quicklook $D_{st}$?

!!Then test it!!
KF (EKF/UKF) based estimation

Solar wind parameters

$D_{st}$ model + EKF/UKF

Estimated $D_{st}$

Quicklook $D_{st}$

True $D_{st}$

Error
KF (EKF/UKF) based estimation

KF based techniques

Model parameters are known

Process and measurement noise covariance are known

Measurement noise was found coloured.
Implementation

\( D_{st} \) index model

- M1: Burton et al. (1975)

- Model parameters are fixed.
- Process & measurement noise covariance are fixed.
Case 1: white noise assumption

true $D_{st}$
+ synthetic white noise

Solar wind parameters

$D_{st}$ model + EKF/UKF

Estimated $D_{st}$

Error

true $D_{st}$
Case 2: measurement coloured noise

Solar wind parameters

$D_{st}$ model + EKF/UKF

Estimated $D_{st}$

Quicklook $D_{st}$

true $D_{st}$

Error

$D_{st}$
Case 1: white noise assumption

nRMSE results

<table>
<thead>
<tr>
<th></th>
<th>all $D_{st}$</th>
<th>$D_{st} &lt; -80$ nT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M1</td>
<td>M2</td>
</tr>
<tr>
<td>no KF</td>
<td>0.5709</td>
<td>0.5047</td>
</tr>
<tr>
<td>KF</td>
<td>0.2729</td>
<td>-</td>
</tr>
<tr>
<td>EKF</td>
<td>-</td>
<td>0.2690</td>
</tr>
<tr>
<td>UKF</td>
<td>-</td>
<td>0.2700</td>
</tr>
</tbody>
</table>

- Using KF based estimation, the error decreases ~ 50%.
- No difference between EKF & UKF.
Case 2: measurement coloured noise

nRMSE results

<table>
<thead>
<tr>
<th></th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
</tr>
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<tbody>
<tr>
<td>no KF</td>
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<td>0.4292</td>
<td>0.5774</td>
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<tr>
<td>KF</td>
<td>0.3701</td>
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<td>-</td>
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<tr>
<td>EKF</td>
<td>-</td>
<td>0.3645</td>
<td>0.3793</td>
</tr>
<tr>
<td>UKF</td>
<td>-</td>
<td>0.3645</td>
<td>0.3795</td>
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<table>
<thead>
<tr>
<th></th>
<th>M1</th>
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<th>M3</th>
</tr>
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<tbody>
<tr>
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<td>0.5441</td>
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<td>0.4069</td>
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<tr>
<td>KF</td>
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<tr>
<td>EKF</td>
<td>-</td>
<td>0.1693</td>
<td>0.2306</td>
</tr>
<tr>
<td>UKF</td>
<td>-</td>
<td>0.1693</td>
<td>0.2308</td>
</tr>
</tbody>
</table>

Using KF based estimation, the error decreases.
No difference between EKF & UKF.
Other KF based estimation for $D_{st}$ index application

- Multiple KFs for process noise covariance estimation.
- Joint and dual estimation for model parameters.
- Noise covariance using dual UKF estimation.
Conclusions

• KF based estimation is suitable for $D_{st}$ index estimation.

• If noise is coloured, shaping filter is required.

Recommendations

• Estimation error can be improved by
  • more accurate $D_{st}$ index model
  • coloured noise $\Rightarrow$ white noise
Thank you